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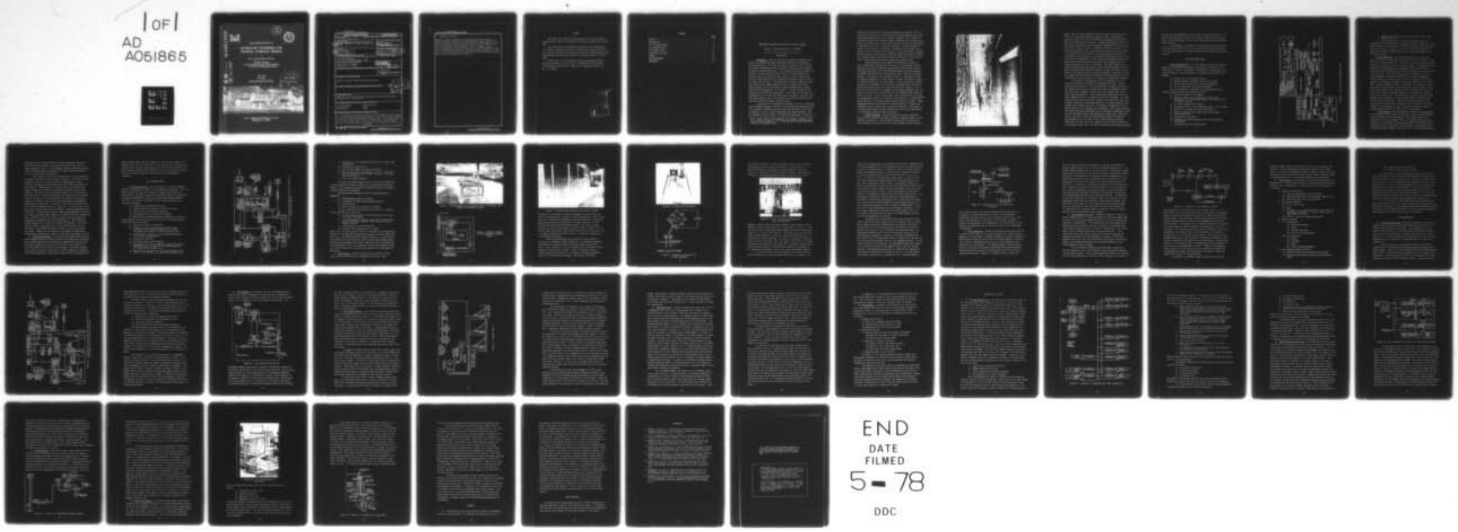

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AUTOMATION TECHNIQUES FOR PHYSICAL HYDRAULIC MODELS

by

Don L. Durham, George C. Downing

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

January 1978

Final Report

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Automated Data Acquisition and Control Systems (ADACS) have been designed and built at the Waterways Experiment Station for the purpose of collecting data and controlling operations of physical hydraulic models. The computer hardware configuration for each system consists of a minicomputer; various peripheral devices such as magnetic tape, disc, card readers, etc.; interval timers; analog to digital converters and multiplexer or Serdex system with interfacing

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20. ABSTRACT (Continued).

equipment; teletype; model control interfacing; and a printer/plotter. The ADACS are capable of automatically calibrating model sensors, controlling model operation, acquiring data from the sensors at a high sampling rate, and analyzing test data. Data are taken and recorded on disc or magnetic tape for direct analyses by the minicomputer system or on magnetic tape in a format compatible with larger computing facilities for backup analyses. Such automation techniques for hydraulic modeling has greatly reduced the time and cost of physical model testing, has improved the quality and quantity of model data, and has allowed more sophisticated procedures for data analyses and model tests than could be performed in the past.

PREFACE

This paper was prepared for presentation at the 1977 Electronic Associates Inc. Users Group Conference, Huntsville, Alabama, 12-14 April 1977.

The authors wish to acknowledge the Office, Chief of Engineers, U. S. Army, for granting permission to publish this paper and the many U. S. Engineer Districts for authorizing the various model studies which supported and used the model automation techniques presented in this paper.

Director of U. S. Army Engineer Waterways Experiment Station during the conduct of the study and the preparation and publication of this report was COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

AUTOMATION TECHNIQUES FOR PHYSICAL HYDRAULIC MODELS

By Don. L. Durham and George C. Downing[1]

INTRODUCTION

1. Background. Over the past decade, automated processing technology has evolved from large, expensive computers to minicomputers and microprocessors. With this evolution, the physical size and cost of automated processing systems have greatly decreased with a minimal decrease in system capabilities. Cost reductions for such systems have resulted in economic justification of the use of minicomputer and microprocessors to a specific task or group of specific operations; whereas, large computers can be justified economically only for multiple operations and tasks. The automation of physical, hydraulic modeling techniques has lagged automation efforts in many other fields mainly because of cost justification and the requirements of highly specialized instrumentation (e.g. sensors). However, needs for such automation have existed for many years. These needs are the result of requirements for (a) real-time model control decisions, (b) quasi real-time data analyses, and (c) more accurate and reliable model data for engineering and environmental interest studies.

One mission of the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station is the physical and numerical modeling of hydraulic problems associated with the activities of the Corps of Engineers, as well as other government and private agencies. The Wave Dynamics Division (WDD) of the Hydraulics Laboratory is primarily

[1] Don L. Durham, Research Oceanographer, and George C. Downing, Supervisory Electronic Engineer, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

concerned with problems involving wave phenomena in harbors, tidal inlets, and on the open coast and the effect of these phenomena on coastal structures (breakwaters, jetties, groins, bulkheads, etc.), harbor oscillations, moored ship response, harbor circulation and flushing, navigation conditions through tidal inlets and harbor entrances, maintenance of navigation channels, and sediment transport. Primary modeling interests of the Estuaries Division of the Hydraulics Laboratory are hydraulic problems associated with estuaries such as maintenance dredging; shoaling; design modifications to existing navigation channels, harbors, and entrance channels; saltwater intrusion; diffusion and flushing patterns of pollutants; and hurricane surge along coastal areas.

Recent increases in the number and complexity of physical model studies conducted each year and the use of such models to solve hydraulics problems of extremely large harbors and estuaries (requiring large model areas) have vividly demonstrated a need for automation of modeling procedures including operation, data collection, and data analysis. The physical size of models (Figure 1) involving the study of long wave phenomena, the vast complex of basins and channels requiring detailed study, and the large number of tests necessary to evaluate the effect of improvement plans on harbor circulation and oscillation eliminate manual procedures for data collection and analysis. For examples, the wave model of Los Angeles and Long Beach Harbors[1] covers an area of 1.1 acres and the tidal model of the Chesapeake Bay[2] covers an area of 6.3 acres. Over the last seven years, the above two divisions in the Hydraulics Laboratory have been very successful in automating[3,4,5] major aspects of its physical models for wave and tidal studies. Major automation efforts were devoted to (a) model control, (b) model data acquisition, and (c) model data reduction and analyses. This paper is a concise status report of major automation efforts within the Hydraulics Laboratory during the past seven years.

2. Model Automation. During the past seven years, there have been four major automated systems developed for physical models in the Hydraulics Laboratory. These automated systems have been given the name "Automated Data Acquisition and Control Systems," whose acronym is

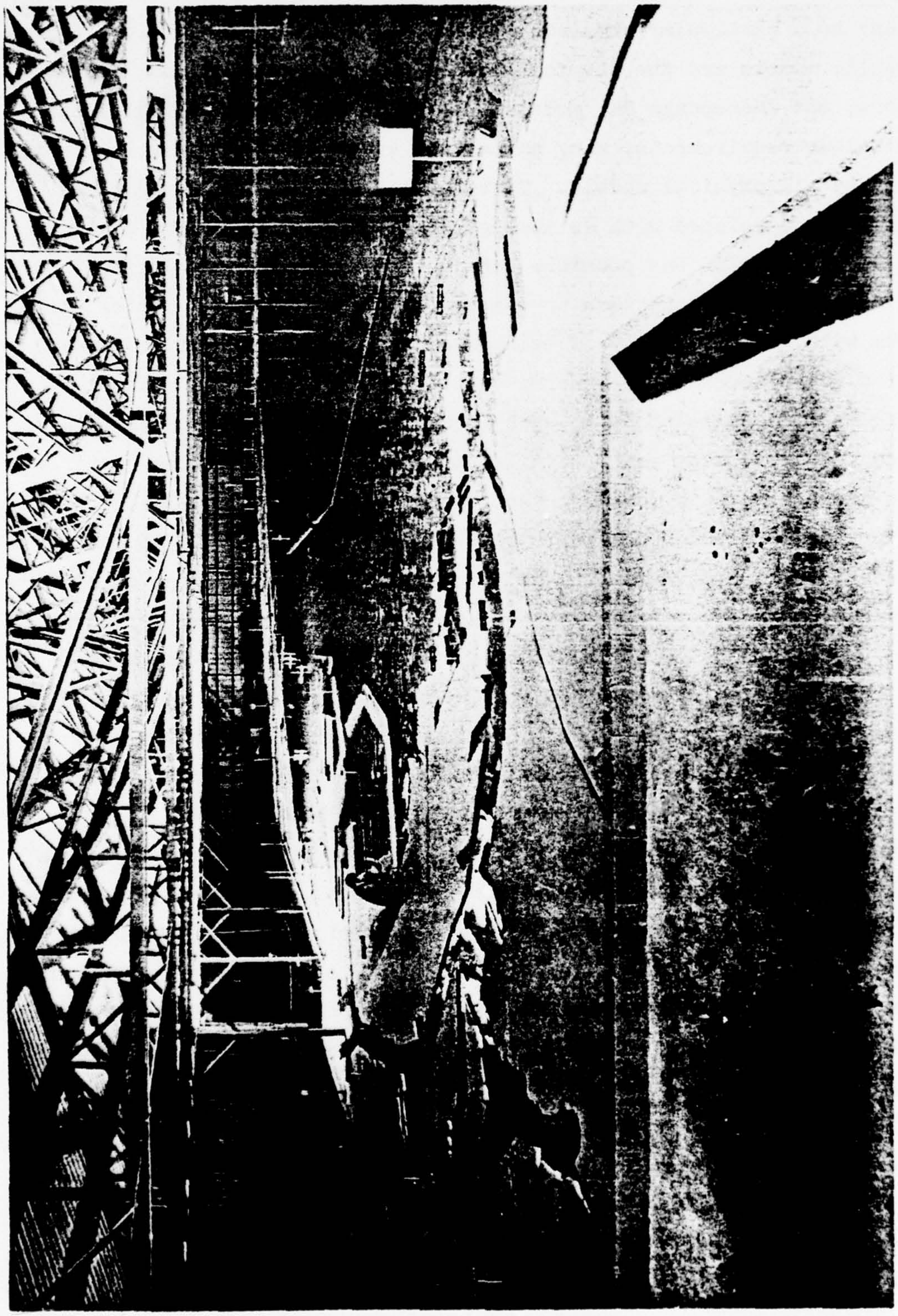

Figure 1. Hydraulic wave model of Los Angeles-Long Beach Harbors

ADACS. Three of these ADACS have been developed for specified applications to a particular physical hydraulic model. These physical, hydraulic models are the New York Harbor, Los Angeles and Long Beach Harbors, and Chesapeake Bay models. Although each physical model has some unique requirements, many automation requirements are similar and shared by all physical models. Therefore, ADACS for the above three models were developed with as much generality and flexibility designed into each system as was possible considering each model's specific requirements. Such approach to the design of each ADACS provides each system with the capability of being used by future physical models and sharing transducers for measuring various model parameters and for making major modifications to each system. The fourth ADACS was designed to handle many small physical models having automation requirements associated with modeling techniques for wave and tidal studies. However, this system's design is nearly identical to the ADACS for the Los Angeles and Long Beach (LA-LB) Harbors with the exception of minor modifications and expansions to the sensors and interfacing equipment.

The general configurations of the four ADACS are the same with the exception of the ADACS for Chesapeake Bay model. Besides having two minicomputers in its configuration, the major difference in this ADACS is the use of a current loop method of transmitting model data and control commands in serial ASCII code between model transducers and a minicomputer. This two-way ASCII communication system is called SERDEX which is an acronym for serial data exchange. For transmission of model data and control commands, the other three ADACS use standard techniques of amplitude modulation of an analog signal whose voltage varies between ± 10 volts. The general configuration of each ADACS consists of the following four subsystems: (a) a data recording and control generating subsystem which is basically a minicomputer with required peripheral devices and appropriate interfacing to other subsystems; (b) model sensors and interfacing equipment for measuring model parameters such as water velocity and/or inflow, salinity, temperature of water and/or air, changes in water surface elevations (waves and/or tides), etc.; (c) model controls and interfacing equipment

for wave and tide generators, inflow valves, sensor calibrations, etc.; and (d) data reduction, analysis, and display subsystem which, in most cases, is the minicomputer in the first subsystem with mass storage and display devices.

The remainder of this paper will be devoted to describing each ADACS with some being described in more detail than others and to discuss their application as to model controls, data acquisition, and data analyses.

NEW YORK HARBOR ADACS

3. System Configuration. The first ADACS, developed for physical models in the Hydraulic Laboratory, was designed[3] to operate on the tidal model of the New York Harbor. A schematic of this system is presented in Figure 2. Its configuration is composed of four basic subsystems:

- a. Digital data recording and controls.
- b. Analog recorders and channel selection circuity.
- c. Various model sensors and interfacing equipment.
- d. Two tide generators and control equipment.

The first subsystem is basically a minicomputer with the following characteristics and peripheral devices:

- a. 16K, 16 bit words of core memory.
- b. Analog to digital pack featuring 50 analog inputs ($\pm$10 volts F. S.), 33 kHz multiplexer, and 12 bit analog to digital converter.
- c. One direct memory access channel.
- d. One digital timer (1 msec resolution) and 4 in-core timers.
- e. Seven (12 bit) digital to analog converters.
- f. Sixteen control lines, 8 sense lines, and 8 general purpose interrupts.
- g. One multiunit controller.
- h. Teletype unit keyboard/printer and 10 cps paper tape reader/punch.
- i. High speed paper tape reader/punch.

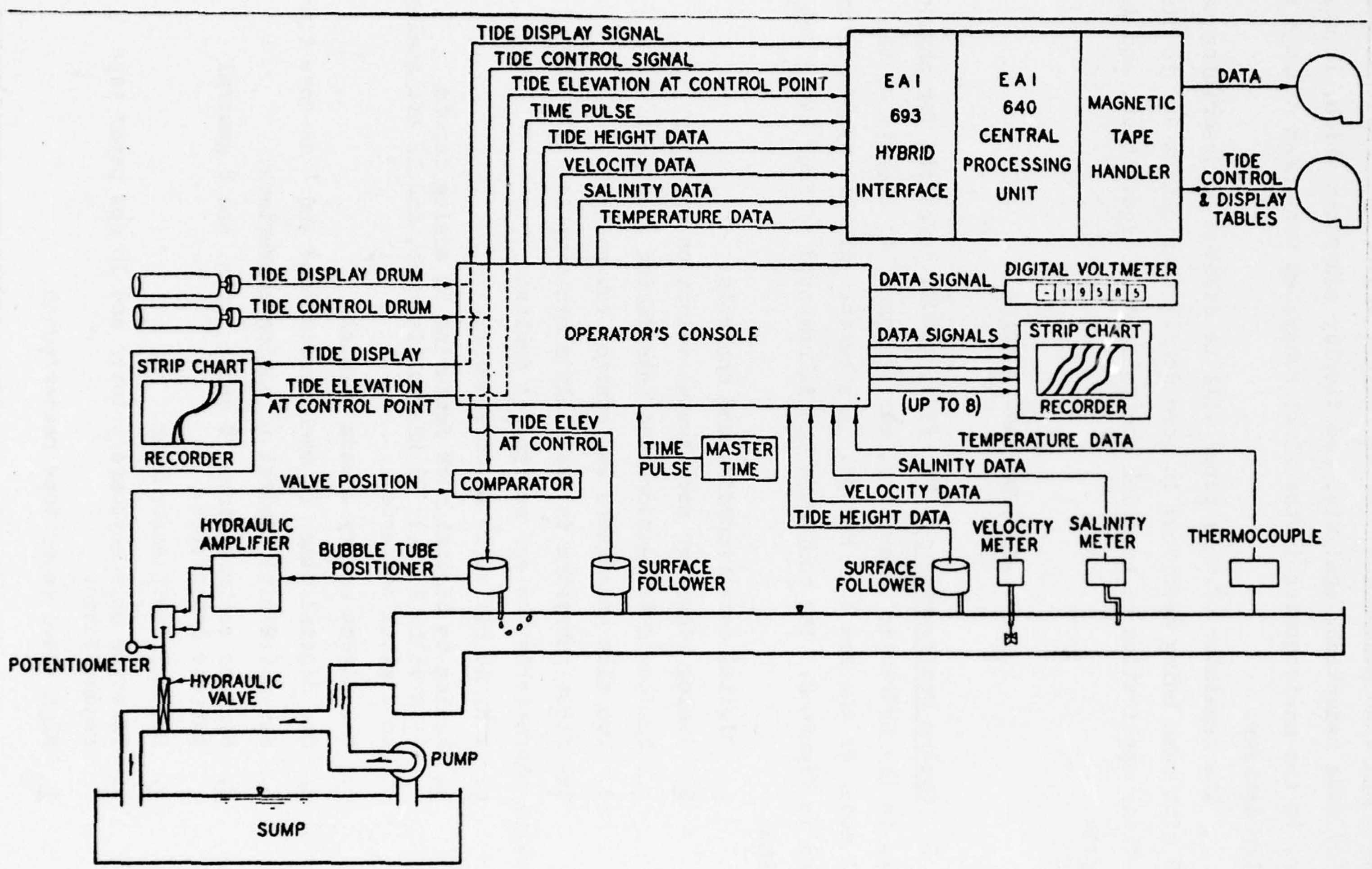

Figure 2. New York model automation scheme

j. Magnetic tape controller with two 9-track magnetic tape drives (12.5 ips).

k. Fixed head data disc (360,000-word storage capacity).

In addition to the digital data recording and controls subsystem, various analog recorders are available to visually display and record selected model data as well as channel selection circuitry (patch panels) for dynamically setting up input/output signals from the minicomputer to the physical model.

4. System Operation. This ADACS had basically two functional tasks which were to control the tide generators at two locations in the model and to acquire data as to water level, velocity, salinity, and temperature at specified locations in the tide model. Tide generation in a tidal model is accomplished by exchanging under controlled flow a specified volume of water between the physical model and a large sump or tidal reservoir. The control scheme for the tide generator is an electro-pneumatic-hydraulic mechanism which accepts a programmable analog voltage as a control signal and uses a feedback control loop to regulate the volumetric exchange of water from the model to the sump. Thus, the water-surface elevation in the model can be forced to reproduce a known tide by appropriately varying the control signal. Since additional information on tide generators is presented in a later section of this paper, a detailed discussion of the generator operation will not be covered here. The ADACS control function for the two tide generators is to supply the correct analog voltage to reproduce the desired tides in the model. These desired tides are generated and stored in the form of tables on magnetic tapes, retrieved by the minicomputer at the appropriate times, and supplied through a digital to analog converter to the controller of the tide generator.

5. Model Sensors. The measurements of required model parameters are collected by various types of transducers with the resulting data being transmitted to the minicomputer as an analog voltage to be digitized and stored on magnetic tape. The output signal from each transducer is an amplitude varying analog signal with voltage varying between ± 10 volts. Digitization of each signal is accomplished by a 50-channel analog to digital converter (12 bit) with multiplexing rates

exceeding 32 kHz. The data which are stored on magnetic tape are not analyzed by the minicomputer but are processed at a later time on a larger computer at the U. S. Army Engineer Waterways Experiment Station (WES). The data analyses performed at the large computer facilities will not be discussed in this paper.

Water surface elevations are measured with a device which was developed at WES and is called a surface follower. This device follows changes in the water surface elevation by high-frequency, small-amplitude oscillations between contact/no contact positions about the water surface. Measurements of the water-surface are obtained from analog voltages which indicate the relative position of the surface follower. This device has an operational range of 0.7 ft and an accuracy of $\pm$0.001 ft. Velocity measurements are obtained from a WES modified Price current meter which indicates flow rates by counting the rotates of the meter's vane over a given time period and producing a proportional voltage output. Direction of water flow is crudely indicated within 180 degree sectors by a drag wire. For tidal flow in channels, such direction resolution is adequate. Salinity measurements are obtained by a commercially available, temperature-compensated conductance cell which continually pumps samples at a constant flow rate through the cell. Each unit consists of a meter and three cells with each cell containing a conductance probe and a thermocouple. Three cells with salinity ranges of 0-2, 0-20, and 0-40 ppt are required to cover the salinity ranges in the model and to provide good resolution at low salinities. The standard deviations of these cells are $\pm$0.5 percent full range. Temperature measurements are obtained with traditional thermocouple probes having a range of 0-200°F with an accuracy of 0.5°F.

6. Future Modifications. With the New York Harbor ADACS being the first automated system for physical models in the Hydraulics Laboratory, much valuable experience and knowledge were gained which could be used in future automation efforts and are reflected in the design of the other three ADACS discussed later in this paper. Some major findings were a need for improved sensors and/or better techniques of measuring various model parameters, requirement of quasi-real-time calibration of

sensors during model testing, a demand for real-time data analyses and graphic output, and the necessity of a bulk storage device and increased thru-put rates for wave model applications. The original equipment for New York Harbor ADACS has been retired and will be replaced in the near future with modern automation techniques and a new minicomputer subsystem.

LA-LB HARBORS ADACS

7. System Configuration. The LA-LB ADACS is the first automated system for hydraulic wave models[4] in the Hydraulics Laboratory. With the physical model of LA-LB Harbors being the largest wave model in the United States, the need for automation techniques became very imperative. The system configuration (Figure 3), which met appropriate design criteria[6] for use in the LA-LB hydraulic model study, consists of the following subsystems:

a. Digital data recording and controls.

b. Analog recorders and channel selection circuits.

c. Wave sensors and interfacing equipment.

d. Wave generator units and control equipment.

The digital data recording and control subsystem is basically a minicomputer (1 μsec memory cycle time) with the following characteristics and peripheral devices:

a. 32K, 16 bit words of core memory.

b. Analog to digital pack featuring 64 analog inputs ($\pm$10 volts F. S.), 45 kHz multiplexer, and 12 bit (including sign) analog to digital (A/D) converter.

c. One real-time clock with a 1 μsec decrementing counter and 4 in-core interval timers.

d. A multiunit controller.

e. Two direct memory access channels.

f. Moving head disc with one removable platter and one non-removable platter (1.1-million word storage capacity, 100 kilowords/sec transfer rate).

g. Magnetic tape controller with two 9-track magnetic tape units (25 ips, 800 bpi, 10 kilowords/sec transfer rate).

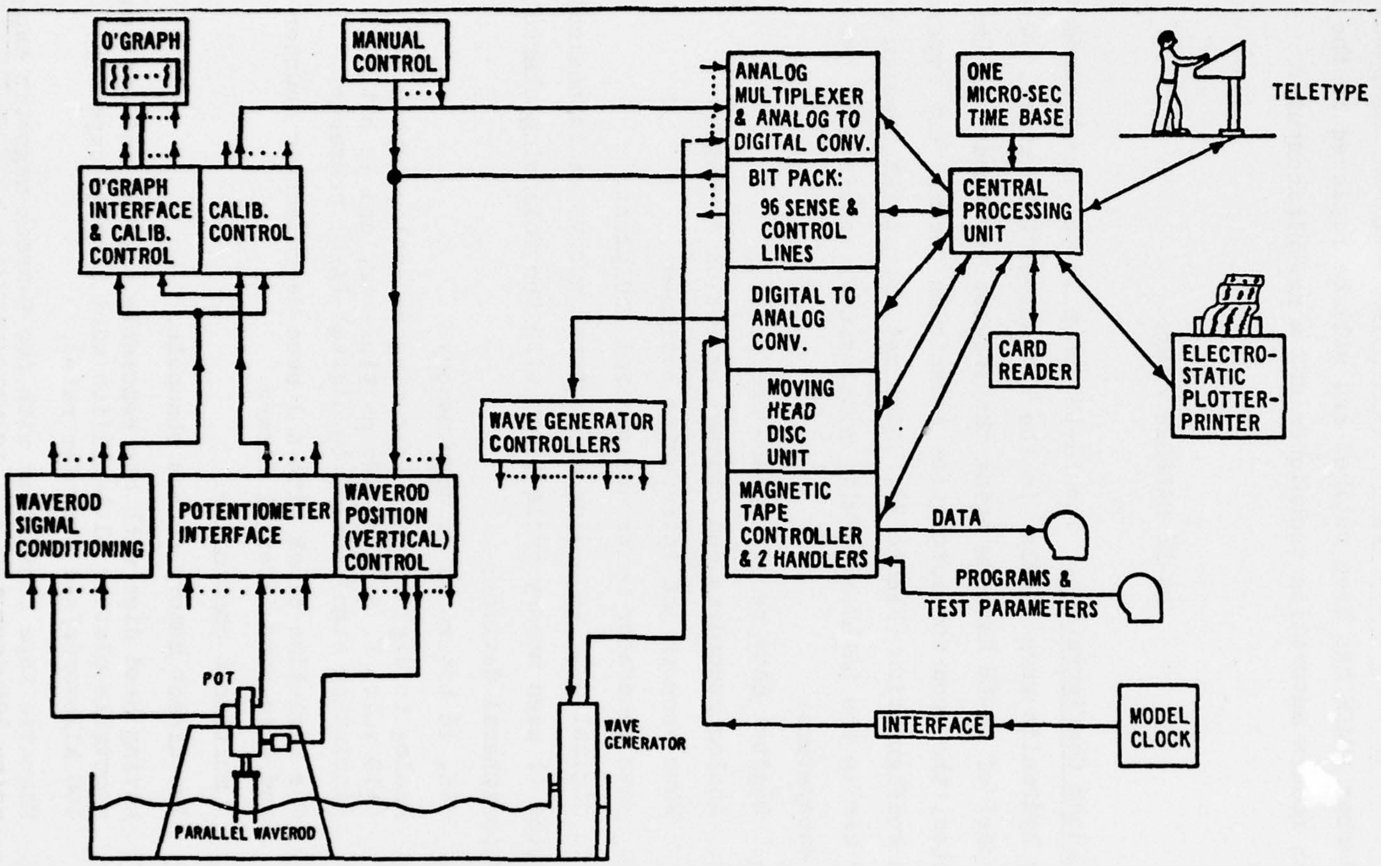

Figure 3. Automated data acquisition and control system (ADACS) for hydraulic wave models

h. Teletype unit with keyboard/printer and 10 cps paper tape reader/punch.

i. 96 sense and control lines.

j. Four (12 bit) digital to analog converters.

k. Matrix electrostatic printer/plotter (print: 1620 lines/min, 132 char./line, and 128 char. set; plot: 4 in./sec and 100 styli/in.).

l. Card reader (300 cards/min).

The analog recording subsystem acts as a backup for ADACS and a visual display for operator inspection of analog signals from wave sensors. This subsystem has manual or automated selection and control of five 12-channel oscillographs.

The wave sensor subsystem includes the following major components:

a. 50 wave-height sensors and stands.

b. 50 channels of signal conditioning equipment.

c. Power supplies.

d. Manual and automatic calibration equipment.

The last subsystem, wave generator and controls, is composed of the following major components.

a. 14 wave generator frames, crossarm assemblies with drive rods, and wave paddles.

b. 14 electrohydraulic actuators with linear voltage differential transformers, hydraulic power supplies, and hydraulic controls.

c. 14 servovalves and servocontrollers.

d. Interface from servocontrollers to ADACS.

Each unit of the wave generator (Figure 4) utilizes an electrohydraulic actuator for driving the wave paddles through the crossarm assembly and drive rods. The electrohydraulic actuator (Figure 5) is controlled by the servovalve and servocontroller which accepts ADACS command signals controlling wave heights and periods. Except for the wave sensors and the wave generator units, all components of ADACS are compactly housed in a trailer (Figure 6) to provide easy control of the environment of the system.

8. Wave Sensors. The data acquired from wave models are the water surface variations about a reference water level. This

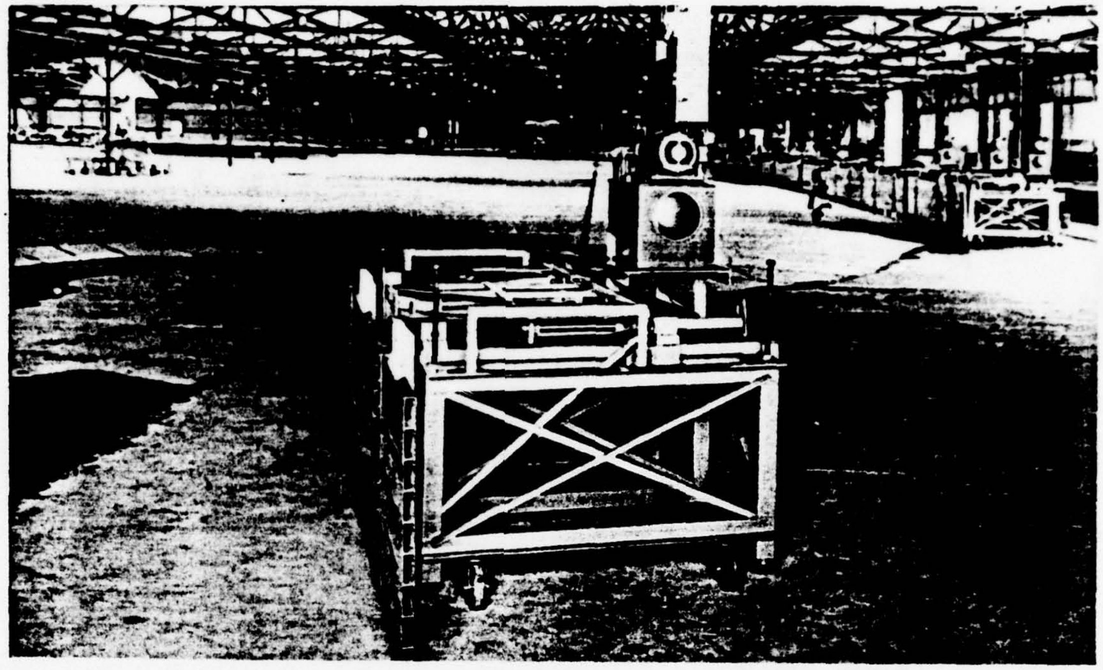

Figure 4. Electrohydraulic wave generator section with frame, wave paddle, and hydraulic supply

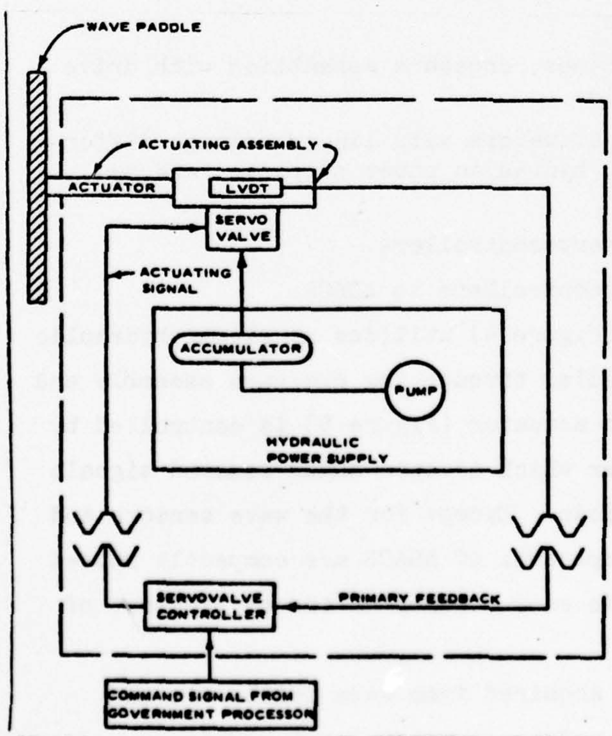

Figure 5. Schematic diagram of electrohydraulic actuator system

Figure 6. Automated data acquisition and control system

information is collected at selected geographic locations within the model for specified wave conditions at the wave generator. Wave sensors are used to obtain this information at selected locations in the model. Water-surface-piercing, parallel-rod wave gages (Figure 7) are the wave sensors used in the LA-LB Harbors model. This type of sensor has been used on past wave models with much success. However, for the present case, this sensor required some modifications to the electronics to increase accuracy and stability and to the physical configuration for automated calibration.

Each water-surface-piercing, parallel-rod wave sensor is connected to a Wheatstone bridge (Figure 8). The transducer measures the conductance of water between two parallel rods mounted vertically. This conductance is directly proportional to the depth of submergence of the two rods in water. Output of each wave sensor is routed through shielded cables to its signal conditioning equipment where it is processed for recording. The output of the signal

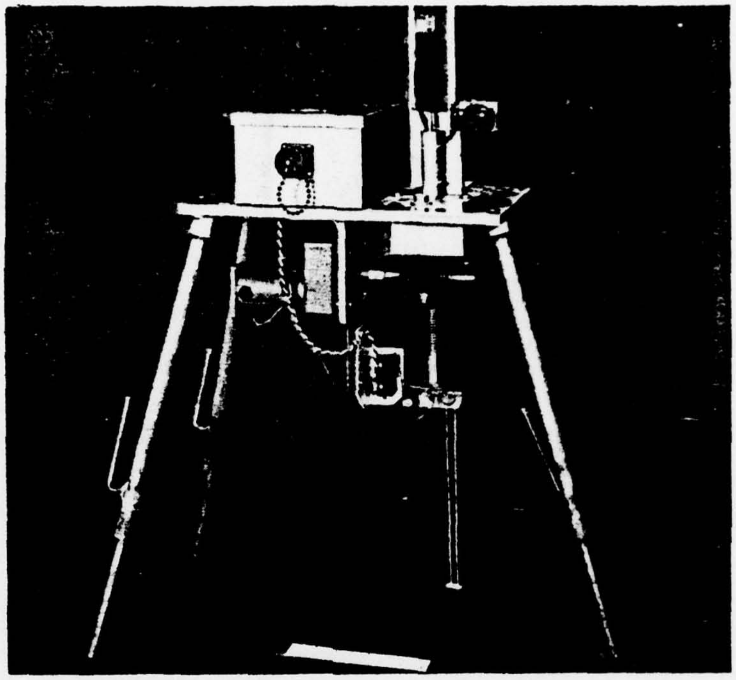

Figure 7. Parallel-rod wave sensor

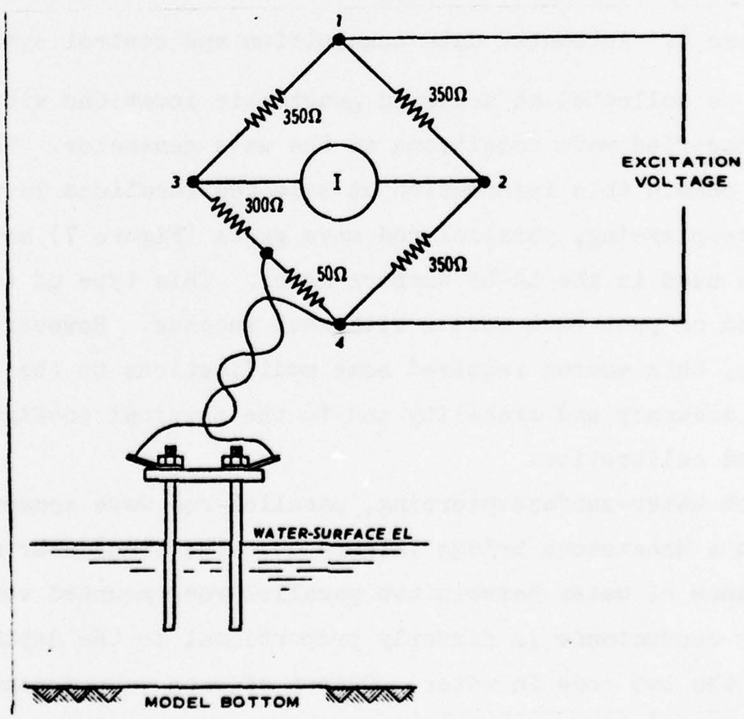

Figure 8. Schematic of parallel-rod bridge transducer

conditioning equipment is connected through shielded cables to analog oscillographs where an analog time history is recorded and to an analog multiplexer of the digital recording subsystem where it is digitized and recorded in a binary format on magnetic tape and/or disc. The signal conditioning equipment (Figure 9) consists of a carrier

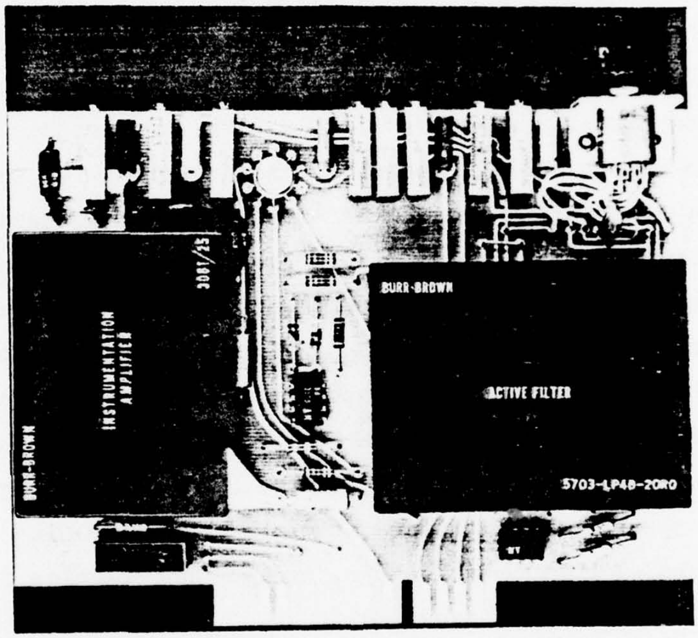

Figure 9. Signal conditioning equipment for wave rod amplifiers

amplifier, filter, and various power supples. This system can detect changes in water surface elevations to an accuracy of 0.001 ft. To obtain this accuracy, ultrastable power supplies and better-than-average signal to noise ratios are necessary. The carrier source for the wave sensor bridge maintains a variation of less than 0.025 percent for a 10 percent power-line variation. The noise in the system is less than ± 5 mv for ± 10 v full range. Thus, the signal to noise ratio is -66 db. To maintain this signal to noise ratio, it is necessary to use shielded cables wherever possible, to discriminate selections of grounds, to use high-quality components, and to have a good maintenance schedule.

To convert the water-elevation data in millivolts to water surface elevations in feet, each wave sensor must be calibrated. The

capability of automatically calibrating the wave sensors (maximum of 25 rods simultaneously) prior to collecting data also is provided by ADACS. In order to calibrate each set of parallel rods, the voltage from the signal conditioning equipment is monitored and recorded as the parallel rods are moved vertically a known distance into or out of the water. A precision, linear-position potentiometer is located on the wave sensor stand and is coupled directly to the parallel rods by a gear-train driven by an electric motor. By moving the coupled wave sensor and potentiometer wiper vertically with the electric motor and by monitoring the output voltage from the potentiometer, the wave sensor can be moved a precise distance. The electric motor for each wave sensor is controlled by a control/sense line and a relay contact. The minicomputer controls the vertical movement of each wave sensor by activating its associated control/sense line. The central processing unit (cpu) acts as a voltage comparator by monitoring the potentiometer voltage and comparing it with a reference voltage which is determined from desired displacement and potentiometer calibration. When the voltage comparison is satisfied, the control/sense line is reactivitated, the electric motor stops, and voltage samples from the rods and potentiometers are acquired.

By systematically moving each wave sensor through 11 quasi-equally spaced locations (Figure 10) over the range of the rod length used, voltage versus known displacements are obtained from which a calibration curve for each sensor can be calculated and recorded on magnetic tape or disc. After collecting the calibration data, the minicomputer analyzes these data by least-squares fitting a set of curves (linear, quadratic, or spline) to the data, determining the best order of fit, and comparing the maximum deviation of the best fit with a previously acceptable value for this maximum deviation. If the fitted curves are not acceptable, the minicomputer flags that channel in the calibration record on the magnetic tape or disc for further analyses. Any malfunctioning sensors are listed on the teletype for the operator to determine the required action (i.e., accept present calibration, clean bad rods, recalibrate, etc.). Having completed

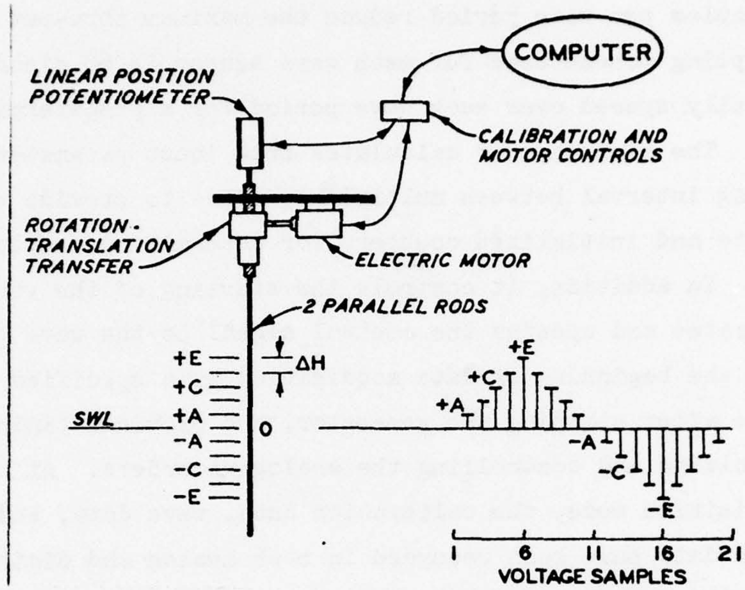

Figure 10. Schematic of wave rod calibration procedure

the calibration mode, the original calibration data for each set of parallel rods and potentiometer as well as the calibration coefficients are written into a file on magnetic tape or disc. Analytical considerations of calibration curve fitting, accuracy of reference potentiometers, and repeatability test of calibration procedures have demonstrated that an accuracy of ± 0.001 ft in wave height is obtainable.

9. Data Acquisition. During the acquisition mode, wave data for a specified wave condition at the wave generator are collected from a maximum of 50 wave sensors, recorded on analog strip charts, digitized, and recorded on magnetic tape or disc for further analyses. In addition, actuator displacement data from the 14 electrohydraulic wave generator units are acquired. The sampling scheme is quite flexible and can be tailored for different applications with maximum thru-put rates theoretically limited by the multiplexer rate (45 kHz) and allocatable buffer size. However, for specific types of tests, the

execution time of applications software and the specified number of discrete samples per wave period reduce the maximum thru-put rate. The present sampling scheme used for each wave sensor is 60 discrete voltage samples equally spaced over each wave period for a predetermined number of periods. The minicomputer calculates from input parameters the required timing interval between multiplexer scans to provide the correct sampling rate and initializes counters for determining completion of wave tests. In addition, it controls the starting of the wave generator units, generates and updates the control signal to the wave generator units, lags the beginning of data acquisition by a specified number of wave periods after starting the generator, and provides timing pulses for synchronizing and controlling the analog recorders. At completion of the acquisition mode, the calibration data, wave data, and actuator displacement data have been recorded in both analog and digital form. These data with a header for test identification and pertinent parameters are available in binary form from disc for direct analyses by the minicomputer or on magnetic tape in a format suitable for backup analyses on the WES Honeywell G-635 computer.

10. Wave Generator Controls. Through the digital to analog converter, ADACS provides to the wave generator an electrical command signal that drives the electrohydraulic actuator at a given frequency and amplitude of displacement. The actuator drives the wave paddle which generates a water wave having the same frequency as the actuator and a wave height proportional to the actuator's displacement. The control signal is a d-c analog voltage that can vary between ± 10 v. The functional form of the control signal can be varied to generate the required wave regime such as monochromatic, spectral, or any time-dependent wave form. The only restrictions on the form of the control signal is the maximum displacement and velocity limitations of the electrohydraulic actuator system.

The desired analog command signal from ADACS is applied to the wave generator control unit (Figure 11) which provides 14 parallel inverted output signals. These output signals are adjusted for selected quiescent and amplification levels and then are applied to the input of

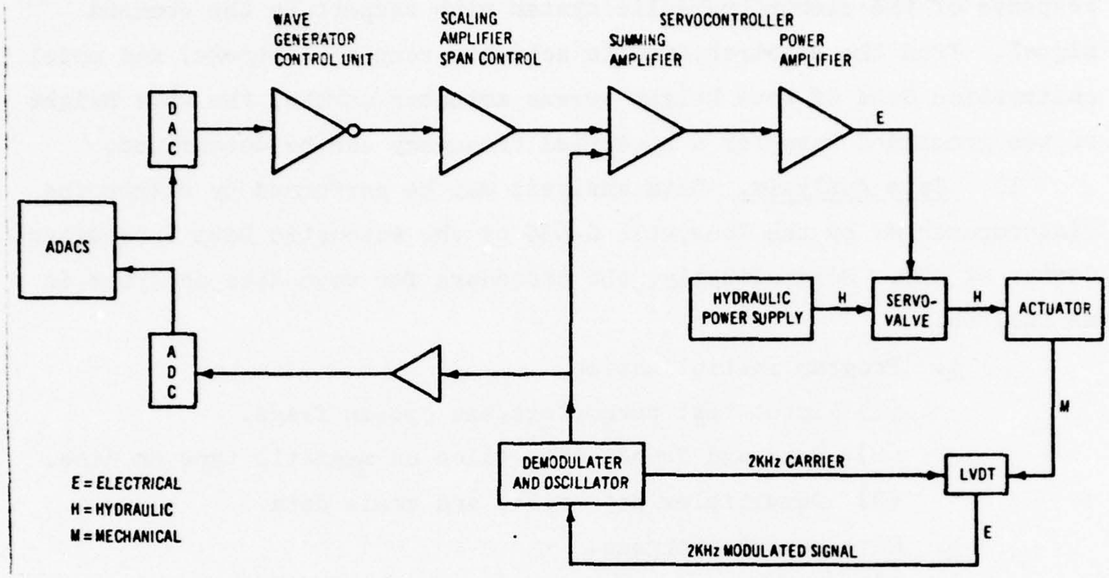

Figure 11. Schematic of wave generator controls

their respective scaling amplifier of the servocontroller. It is in this section of the servocontroller with the span control potentiometer that the system is calibrated for a ± 6.000-in. stroke for a ± 10.000-v command signal. This calibrated command signal along with the actuator position feedback signal is applied to the summing junction of the servocontroller. The algebraic sum of these two signals is then applied to a power amplifier which is suitable for driving the coil of the servovalve. The servovalve controls the flow of hydraulic fluid to the cylinders in the actuator; thus, the displacement of the piston is proportional to the electrical command signal. The actuator position feedback transducer, a linear variable differential transformer (LVDT), provides a modulated 2-kHz output which is proportional to the actuator position. This feedback signal is demodulated and then calibrated for a scale factor of approximately 1.66 v/in. Therefore, the feedback signal along with the loop gain is used to stabilize the closed loop electrohydraulic system, thus ensuring that the actuator tracks the command input within the desired accuracy.

In addition, the feedback signal is applied to the analog

digital converter (ADC) of the ADACS where it is used to compute the response of the electrohydraulic system with respect to the command signal. From the electrohydraulic actuator response (stroke) and model calibration data of wave height versus actuator stroke, the wave height of the generated wave for a specified frequency can be determined.

11. Data Analysis. Data analysis may be performed by either the minicomputer or by the Honeywell G-635 of the Automatic Data Processing Center at WES. Schematically, the procedure for wave data analyses is as follows:

a. Program initialization.

(1) Input test parameters and option flags.

(2) Read and decode data files on magnetic tape or disc.

(3) Demultiplex data files and scale data.

b. Wave record analyses.

(1) $\bar{H} \pm \sigma_H$ and $\bar{T} \pm \sigma_T$.

(2) H_{RMS} .

(3) H_x where x is a specified percent of the highest wave heights, normally $X = 0.333$; thus, $H_{1/3}$ is significant wave height.

(4) Option to plot wave heights versus time.

c. Fourier analyses.

(1) Autospectrum.

(a) Amplitude-frequency.

(b) Energy.

(c) Spectral smoothing.

(d) Plots of above parameters.

(2) Cross spectrum.

(a) Energy.

(b) Coherency.

(c) Phase.

(d) Plots of above parameters.

d. Least-squares harmonic analysis.

(1) Amplitude and phase for specified wave period.

(2) Relative phases and amplification factors between gages.

(3) Analysis of residual variance.

(4) Graphic output of above results.

The analysis of actuator displacement data is basically the above least-squares harmonic analysis from which can be determined the actuator response. Analyses of wave data collected at specified locations on the model are performed most often using steps a and b of the above procedure. Results of the data analyses can be plotted by electrostatic printer/plotter on minicomputer or by pen plotter or CRT plotter (microfilm and hard copy) on the Honeywell G-635 system. For each model test, original data and analyzed results of all tests are permanently stored on magnetic tape and disc files for future reference, additional analyses, and data table generation for reports, etc.

With the analyses of wave records from various harbor locations, amplification factors or harbor responses for various input wave conditions are estimated. These results provide the hydraulic engineers with the basic data whereby the effects of various proposed expansions and modifications to existing harbors can be evaluated.

MULTI-MODEL ADACS

12. System Configuration. The multi-model ADACS was designed to automate model controls and model data acquisition and analyses for several small wave and/or tide models. The configuration of this system is nearly identical to the LA-LB ADACS with expanded capabilities to control tide generators, calibrate tide sensors, and acquire tidal data. The system configuration is presented in Figure 12 and has the same basic four subsystems of LA-LB ADACS with some additional capabilities.

The first subsystem is basically a 32K, 16 bit word minicomputer with I/O and storage devices, analog/digital packages, and a timing package. Details of this subsystem were presented by Durham and Greer (1975). The analog recording subsystem is (a) a backup for the digital data recording subsystem and (b) a visual display for operator inspection of analog signals from model sensors. This subsystem has

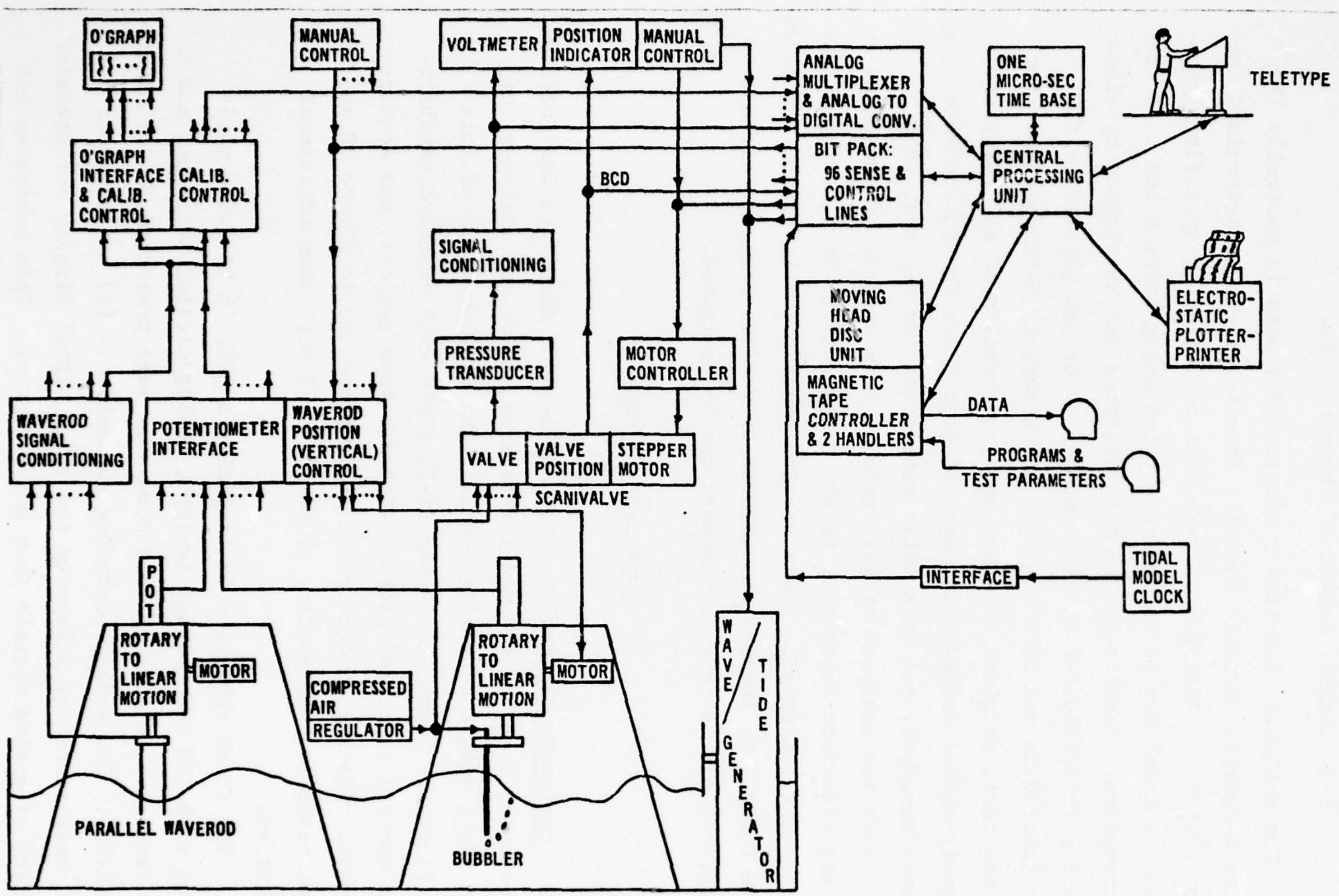

Figure 12. Automated data acquisition and control system (ADACS) for hydraulic wave and tidal inlet models

manual/automated selection and control of five, 12-channel oscillographs and a test point center for manually monitoring a selected channel as to system setup, calibration, and signal condition.

The model sensor subsystem includes instrumentation for both wave and tide sensors. Details of the wave sensor subsystem and calibration procedures were presented in the above discussion of LA-LB ADACS; therefore, discussion of this ADACS will be devoted mainly to its application to tide models. The sensor subsystem for tidal heights includes the following major components:

a. Bubble tubes, stands, and high pressure supply.

b. Scanivalve with manual and automated controls.

c. Precision pressure transducer.

d. Power supplies and signal conditioning equipment.

The last subsystem includes controls for both wave and tide generators. Controls for both mechanical and electrohydraulic wave generators can be provided by ADACS. Start/stop commands are available for mechanically gear-driven wave generators; however, controls for wave period and amplitude must be supplied manually. Although no electrohydraulic wave generators are operational with this multi-model ADACS, this system could provide a programmable analog voltage as a command signal to the servocontroller of such electrohydraulic actuators. The wave period and amplitude for such wave generators are controllable by ADACS.

The command signal to the tide generator is a programmable analog voltage which is supplied by ADACS through one channel of the digital to analog converter. The tide generator has the option of receiving this command signal from ADACS or accepting an analog voltage from a programmable cam and reference potentiometer arrangement. This latter control scheme is used as a backup or alternate control to the ADACS control and until recently has been the primary control of tide generators prior to installation of ADACS. In addition to the command signal, the tide generator has four other major components which are (a) differential amplifier and power supply, (b) bubble tube positioner, (c) hydraulic-pneumatic amplifier, and (d) hydraulic cylinder and flow-control gate assembly.

13. Tide Generator. Basically, the tide in a physical model is generated from cyclic exchanging by controlled flow a predetermined volume of water between the physical model and a tidal reservoir (sump). Figure 13 is a schematic of the tide generator and controls. The

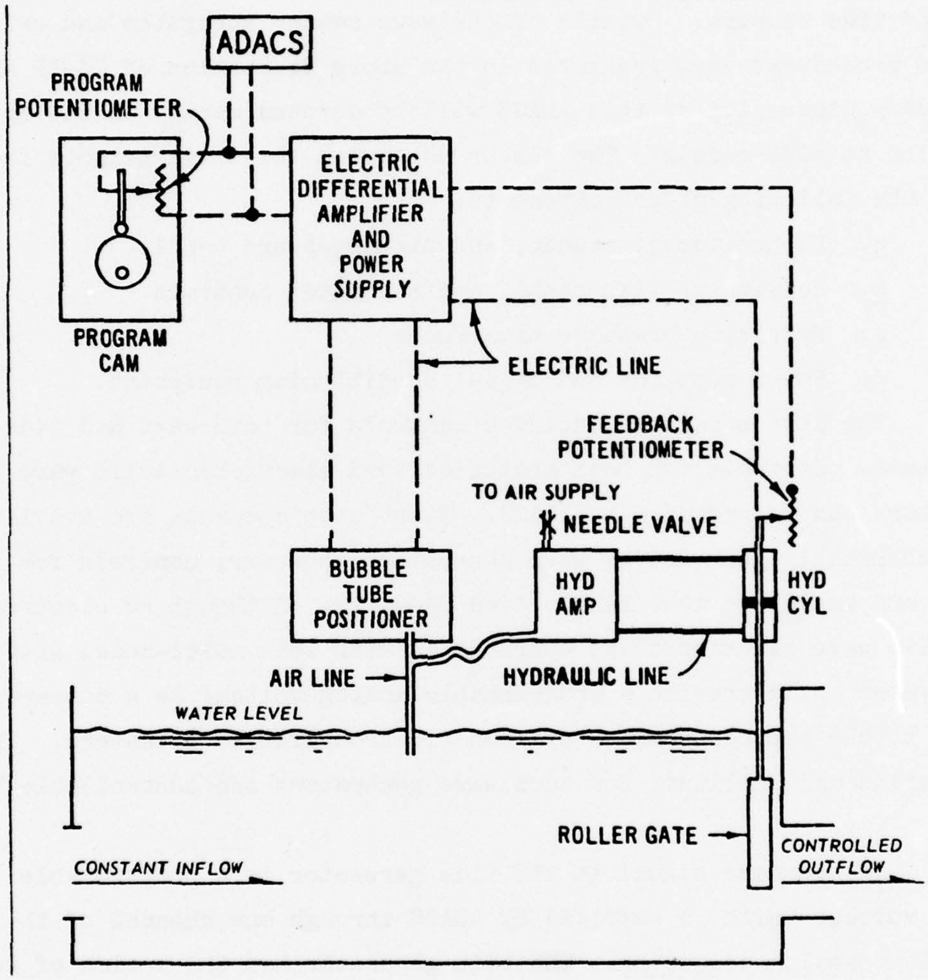

Figure 13. Tide generator and controls

programmed command signal causes a change in the vertical position of the bubble tube relative to the water level in the model. This position change perturbs the equilibrium position of the pneumatic-hydraulic amplifier and results in a differential hydraulic pressure applied to the hydraulic cylinder activating the flow-control gate. The movement of the flow-control gate is in a direction to correct the perturbed equilibrium condition of the pneumatic-hydraulic amplifier by changing

the water surface elevation in the tide model. A feedback circuit from the hydraulic cylinder to the differential amplifier/bubble tube positioner provides a "damping effect" to prevent gate overshoot and unstable oscillations. Thus, any tidal constituent or progressive tide can be used as the forcing function for the tide model by programming ADACS to produce a command signal harmonically representing the appropriate forcing function.

14. Tidal Height Sensors. Data, which are acquired by ADACS from tidal inlet models, consist of time histories of water surface variations relative to some reference water level. For specified tide conditions at the generator, tidal elevations are collected at selected locations within the tidal model. These data are used to calculate mean tide levels, tidal ranges, arrival times of high and low water, and the phases and amplitudes of specific tidal constituents. Although various types of tidal height sensors are used by the Hydraulics Laboratory, a relatively inexpensive tide sensor system was developed and implemented with this ADACS and has been labeled the "bubbler system." This system measures small hydrostatic pressure changes associated with changes in tidal elevations in the model and consists of a high precision, pressure transducer, a scanivalve device for sequencing input ports, and 48 pressure inputs.

To employ the bubbler system (Figure 14), a small plastic tube is inserted some small distance into the water. The outside diameter of this bubble tube is required to be small to minimize blockage of tidal flow, etc. The tube is connected through a throttling valve to a regulated pressure supply. This valve or restriction serves to regulate air flow and isolate the bubble tube from other bubble tubes and the supply pressure. Each bubble tube is connected to a common pressure transducer, which is parallel with the throttling valve and high pressure source, of suitable pressure range to accurately detect the tube's internal pressure changes associated with changes of water surface elevation.

To allow many bubble tubes to share a common pressure transducer, a multiplexing device, which is called a scanivalve, is used. This device multiplexes sequentially many pressure inputs to a common output port. A high precision pressure transducer is included as an

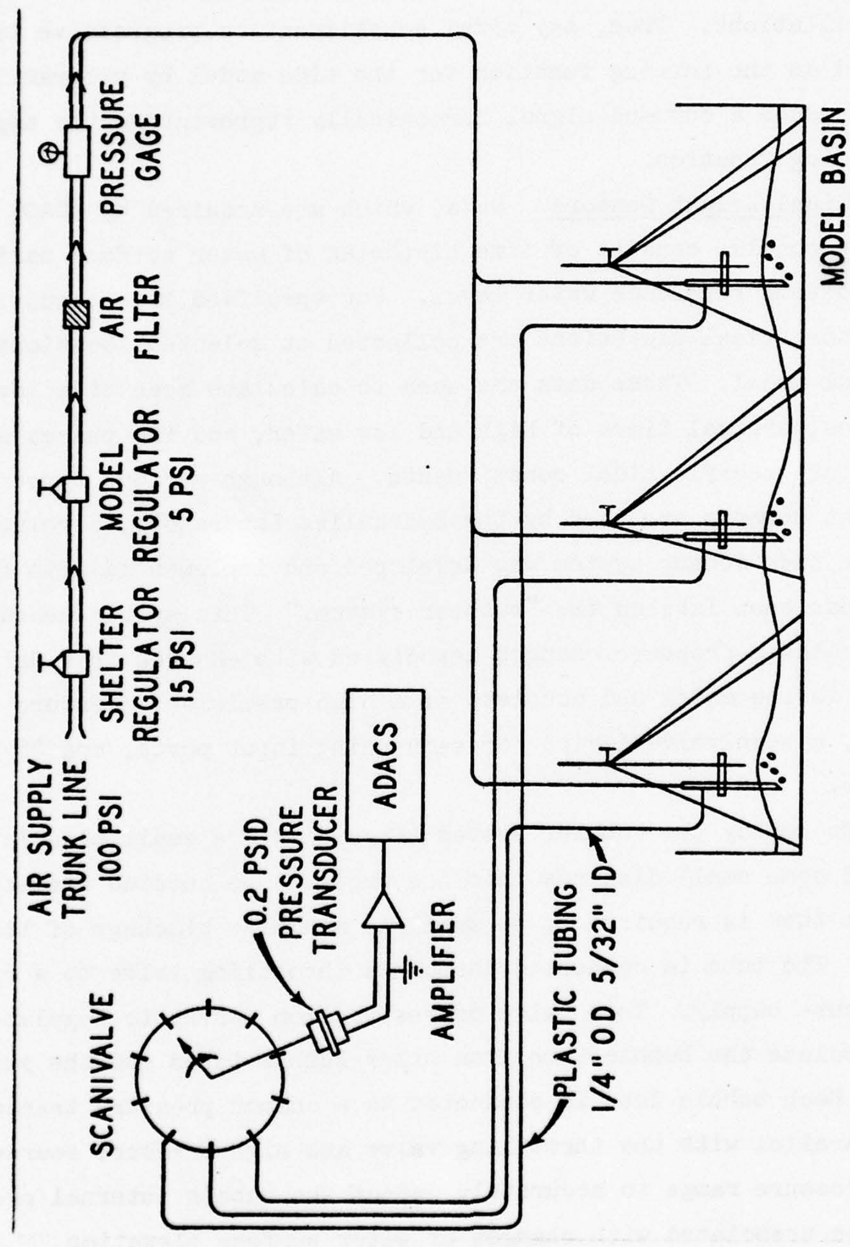

Figure 14. Bubbler system

integral part of the output port. A controller is used to advance the unidirectional stepping motor which increments the scanivalve. By contact closures or commands from ADACS, the valve can be advanced sequentially to any input port or to a "home" (reference) position without intermediate stops.

The system which is presently used is capable of accepting up to 48 pressure inputs and includes a +0.25 psid pressure transducer with a nonlinearity and hystersis (best straight line) of 0.05 percent full scale. The pressure transducer output is an analog voltage of +10 v full scale. The pressure cell is interfaced through appropriate signal conditioning equipment to the analog multiplexer of the digital recording subsystem. The valve accepts both home and step commands from the ADACS and has a BCD position feedback to ADACS. The system can be completely controlled by either ADACS or manual controls.

To install the bubbler system in the model, the water level in the tidal model is raised to mean higher high water (MHHW). At this still-water level, the orifice of the bubbler is inserted into the water to a depth which is slightly greater than the maximum expected tidal range (hydrostatic head). At this elevation, the pressure supply must be set high enough to cause the emission of air bubbles from the tube. For these conditions, the tube's internal pressure is equal to the hydrostatic pressure of the water column above the orifice of the bubble tube. The tube orifice is cut diagonally to aid in the bubble's escape. It is important that the system bubble freely at this depth because the tube's internal pressure ceases to be equal to the hydrostatic head with bubble cessation. At this point, the bubble tubes should be observed over several tidal cycles to be certain there is a continuous stream of bubbles.

The bubbler system with the arrangement of bubble tubes, scanivalve, and a high precision pressure transducer provides a very economical system of obtaining precise measurements of water surface elevations at a large number of locations in a tidal model. Tidal elevation measurements by this system are accurate to 0.001 foot. The sampling sequence of the scanivalve is rated at a maximum of 10 samples per

second. This method of detecting changes of water surface elevation is limited only by the frequency response of the system and the accuracy of the pressure transducer. Application of this system to tidal models has resulted in large dollar savings when 5 or more locations in a model are instrumented.

15. Data Acquisition. During the acquisition mode, tidal data for a programmed tidal condition at the generator are collected from a specified number of tide sensors, digitized, and recorded on magnetic tape or disc for further analyses. The sampling scheme is flexible and can be tailored for different applications with maximum thru-put rates theoretically limited by the multiplexing rate of the scanivalve. The present sampling scheme is to (a) increment the scanivalve to the first data channel, (b) delay a specified time interval (normally 0.5 sec) to allow input pressure to stabilize, (c) collect a specified number (normally 10) of samples, (d) average these voltage samples, (e) store the discrete sample in memory, (f) increment to the next channel, (g) repeat the above procedure, and (h) continue sequentially through remaining channels. For each tide sensor, 100 discrete voltage samples are collected at equally spaced intervals over each tidal cycle for a predetermined number of cycles (normally 3 to 5). The minicomputer initializes counters for determining completion of tidal tests and calculates from input parameters (a) the required timing interval between multiplexing scans of the scanivalve to provide the correct sampling rate, (b) the delay interval at each channel, and (c) the number of voltage samples to be digitized and averaged. In addition, it provides an analog command signal through the digital to analog converter to the tide generator and lags the beginning of data acquisition by a specified number of tide cycles after starting the generator.

Due to thermal effects (zero drift) on the transducer output over a tidal test of 2 to 3 hours duration, the pressure transducer is calibrated prior to and at selected time intervals during each tidal test to provide accurate, update calibration data for scaling voltage (pressure) to tidal elevations. The calibration data are obtained by monitoring three constant pressure values over the tidal range. These

values are obtained by setting a bubble tube at each of the following three tide levels: mean lower low water, mean tide level, and mean higher high water. The three bubble tubes are positioned to these levels in a stilling basin which is connected to the tidal model by a cutoff valve. Prior to each tidal test, the water level in the model and stilling basin are raised to mean higher high water. The stilling basin is then isolated from the model by closing the cutoff valve. Finally, the three bubble tubes are adjusted to their appropriate water depth. Throughout the tidal test these bubble tubes are monitored at every scan to provide update calibration data. During data analysis, calibration information can be updated by calculating calibration coefficients for each scan or any multiple of scans.

A limited number of channels of tidal velocity can be measured by miniature, electromagnetic current meters which are monitored by ADACS. The collection of tidal velocities using ADACS has not been fully implemented at this time and is pending the completion of transducer evaluation. Until such time, the majority of tidal velocity measurements are obtained manually by using a modified version of the miniature Price meters.

In addition to tide data, many tidal inlet studies require wave information as well. The generation of waves and collection of wave data at specific tidal phases (normally high, low, and mean tide levels) are provided by ADACS. While controlling the tide generator and collecting tidal data, ADACS uses in-core timers to determine the occurrence of specified tidal phases at which time (a) the wave generators are turned on, (b) wave data at a specified sampling rate for a predetermined number of wave periods are collected at various locations in the model, (c) the completion of wave test for that tidal phase is detected, (d) the wave generators are turned off, and (e) in-core timers initialized to determine the next specified tidal phase for wave tests. These wave tests are performed normally during the middle cycle of a three-cycle tidal test. The instrumentation and procedure for collecting wave data are the same as described in earlier sections of this paper.

At completion of the acquisition mode, the calibration, wave, and tide data have been recorded in binary form on magnetic tape or disc. These data with a header for test identification and pertinent parameters are available from disc or magnetic tape for analyses.

16. Data Analyses. Analyses of the elevation and velocity data from tidal model are performed by either the minicomputer subsystem or a Honeywell G-635 of the Automated Data Processing Center at WES. Schematically, the automated procedures for analyzing tidal data are as follow:

I. Program Initialization

(1) Input test parameters and option flags.

(2) Read and decode data tape or disc file.

(3) Demultiplex data files and scale data.

II. Tidal Data Analyses

(1) Harmonic analysis using Least Squares Techniques.

(a) Amplitude and phases of tidal constituents.

(b) Relative phases between gages.

(2) Analyses of residual variances.

(a) Original versus Least Square estimate.

(b) Prototype tide versus model tide.

(c) Model base test versus model plans.

(3) Graphic output of above results.

In addition to the above automated procedures, manual and photographic techniques are employed in tidal models to study general patterns of tidal circulation and to define qualitatively littoral transport and deposition patterns.

The analyses of wave data, which are generated and acquired at select tidal phases and/or tidal ranges during specific tide/wave tests in the tidal model, are similar to the procedures discussed earlier. These procedures are basically auto-spectral and cross-spectral analyses, statistical analyses for wave heights and periods of wave signals at selected locations throughout the model, and computation of response functions or amplification factors from wave energy within the harbor or tidal inlet relative to incoming wave energy.

CHESAPEAKE BAY ADACS

17. System Configuration. The ADACS for the large tidal model of the Chesapeake Bay[7] and its numerous tributaries is the most recent automation of a physical model for the Hydraulics Laboratory. This physical model is the largest tidal model in the world. It has approximately 9 acres of poured concrete and is housed in a shelter covering nearly 15 acres. With such a large model area, automated model control and/or data acquisition are required at numerous model locations which may be separated a large distance from each other and/or the central control and recording subsystem. With such large distances over which to transmit model data and control signals, several methods of transmitting electrical signals were reviewed as to their capability of minimizing signal distortion (noise) and their requirement for cables and wiring configurations. The selected method of data transmission was a current loop technique by which serial ASCII (American Standard Code of Information Interchange) data are transmitted or exchanged between a minicomputer and various model devices over a twisted-pair cable via a 4 to 20 ma current loop. This type of data communication is commerically available and has been given the name serial data exchange whose acronym is SERDEX. The use of this SERDEX communication system in the Chesapeake Bay ADACS is the most unique feature of this ADACS when compared with the three ADACS previously discussed. Except for the addition of SERDEX, the overall configuration (Figure 15) of this ADACS has the following general subsystems which are similar to those for the other three ADACS:

a. Digital data recording and controls.

b. SERDEX communication system.

c. Model sensors and interfacing equipment.

d. Tide generators and control equipment.

For the Chesapeake Bay ADACS, the digital data recording and controls subsystem has two minicomputers versus only one for other ADACS. One minicomputer is used for model control and data acquisition with the other minicomputer devoted to data reduction and analyses. In addition, these two minicomputers have the capability of time-sharing the

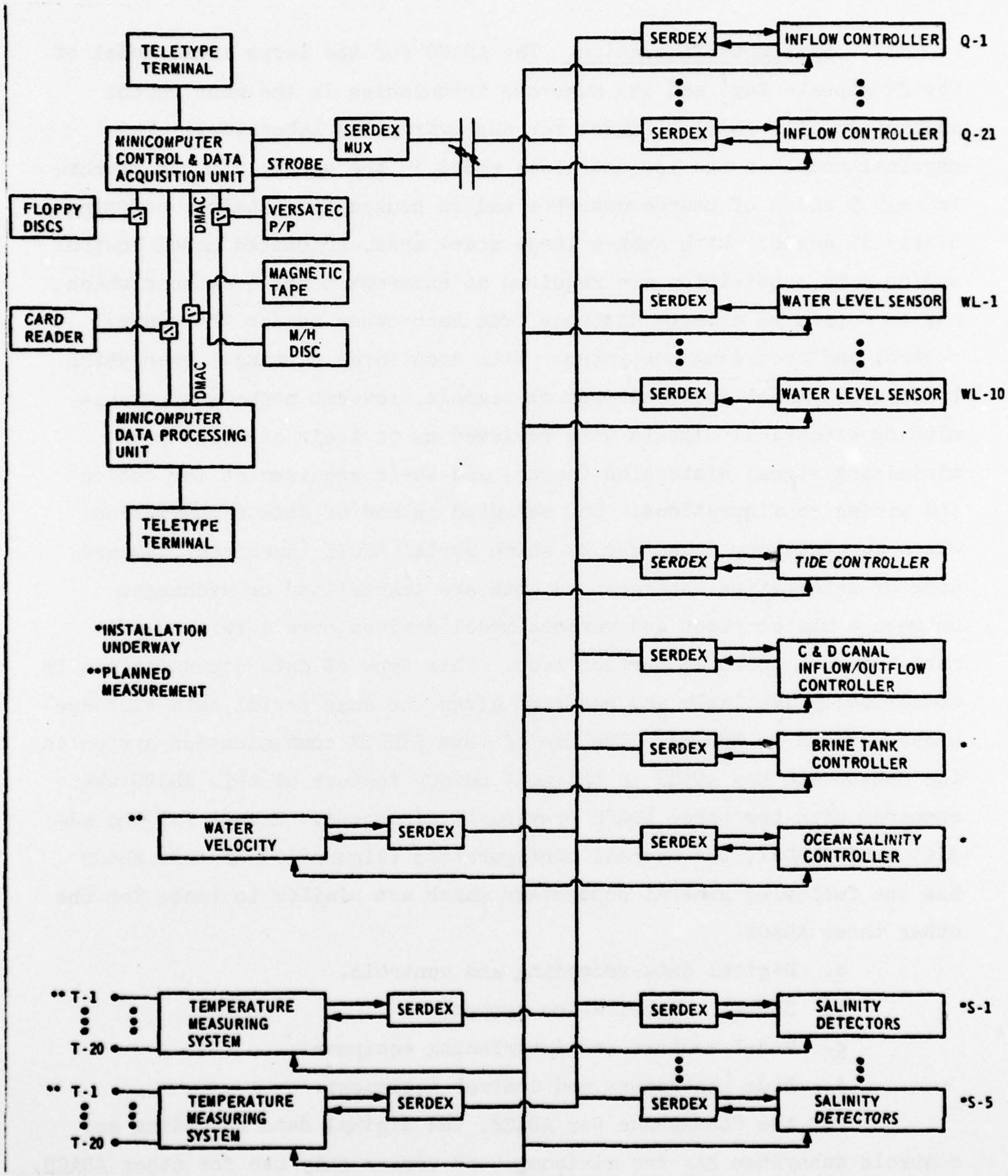

Figure 15. Schematic of Chesapeake Bay ADACS capabilities

same set of pheripheral devices. The arrangement of minicomputers and peripheral devices are illustrated in Figure 15 which presents the capabilities of this ADACS. Specific characteristics of these minicomputers and peripheral devices are as follows:

a. Data acquisition and control minicomputer with 40K, 16 bit words of semiconductor memory, two interval timers with 1 msec decrementing counters, and one direct memory access channel with cycle-stealing 8 channel input capability.

b. Data reduction and analysis minicomputer with 56K, 16 bit words of semiconductor memory, one interval timer with 1 msec decrementing counter, and one direct memory access channel with cycle-stealing 8 channel input capability.

c. Moving head disc with one removable plotter (1.25-million word storage capacity, 90 kilowords/sec transfer rate).

d. Magnetic tape controller with one 9-track tape unit (45 in./sec, 800 bpi).

e. Two teletypes with keyboard/printer (30 cps) and dual cassette tape drives (1200 band).

f. Card reader (300 cards/min).

g. Matrix electrostatic printer/plotter (1.2 in./sec, 100 styli/in.).

i. Two Floppy Disc (125 kilowords storage, IBM compatible, 15 kilowords/sec transfer rate).

j. Serial data exchange interface (current loop, full duplex, 4800 baud) for acquisition minicomputer.

Each minicomputer has a teletype but all peripheral devices can be time-shared by each minicomputer.

The SERDEX communication system includes at present the following major components:

a. One computer multiplexer.

b. 9 model multiplexers.

c. 36 transmitters (Tx).

d. 23 receivers (Rx).

The number of multiplexers and Tx-Rx units can be expanded without limitations to meet model controls and data acquisition requirements.

The third subsystem, model sensors and interfacing equipment, is basically composed of the following components:

a. 10 water level sensors.

b. 21 digital inflow valves.

c. 21 flowmeters.

d. 5 salinity probes

e. Power supplies and various digital and analog interfacing equipment to the SERDEX communications subsystem.

f. Synchronous data acquisition strobe signal.

Additional model sensors for water temperature and velocity are presently in the planning stages for this ADACS.

The tide generator and controls subsystem consist of two tide generators located at the Chesapeake and Delaware Canal and the ocean entrance of the Chesapeake Bay. These tide generators are very similar in design and operation to those previously described in the discussion of the multi-model ADACS. Therefore, these generators will not be discussed in this section. In addition to the tide generators and controllers, each generator has a SERDEX interface and synchronizing strobe for updating the generator controls and acquiring tide elevations.

18. SERDEX Communication System. The SERDEX communication system (Figure 16) is a multiple-loop, multiple-rank, two-way data transmission link between the minicomputer and model sensors and controls. Data in serial ASCII are transmitted between the minicomputer and model sensors over twisted-paired cable via 4-20 ma current loop. The computer multiplexer is the hub of the system and has a full duplex, current loop link between it and the data acquisition and control minicomputer. These two current loops are connected to a terminal strip at the computer multiplexer where multiple-loop, half duplex, current loops to model multiplexers originate. At present, only five, half duplex, current loop networks are connected to the computer multiplexer which has the capability of handling a total of eight. Each of these five loops run to model multiplexers which are located at strategic positions on the model. In turn, each of the model multiplexers have the capability for eight, half duplex, current loops which terminate at another model multiplexer or various model sensors and control devices. This cascading of model multiplexers could continue without restriction until sufficient number of current loops were created to meet model sensor requirements.

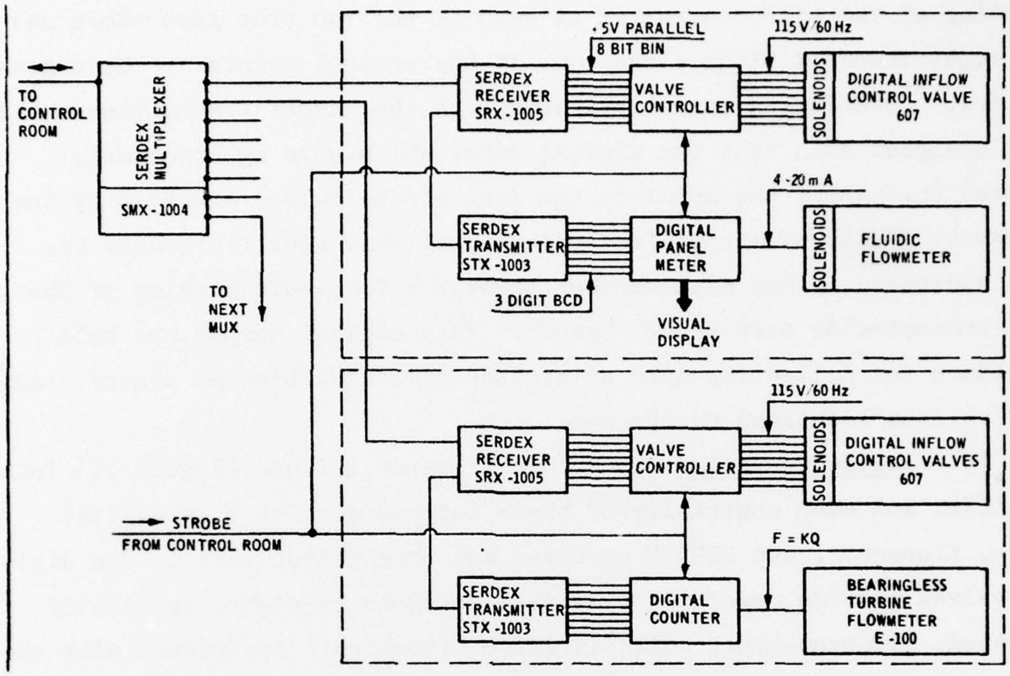

Figure 16. Data communications schematic for Chesapeake Bay Model

At each model sensor or control device the current loop connects with a transmitter and/or receiver unit. The transmitter is interfaced with the transducer so that either analog or pulse-train formatted data is converted to parallel Binary Coded Decimal, BCD, for transmitter input. The transmitter converts the BCD data to serial ASCII for transmission to the minicomputer upon command. The receiver accepts serial ASCII from the minicomputer and converts it to parallel BCD which may be used to control directly some digital device or function or be interfaced by a digital to analog converter to control some analog device or function. The commands initiated by the minicomputer control (a) digital valves, and (b) tide generators. The received data is from (a) flowmeters, (b) water level (tide) sensors, and (c) salinity probes. Associated with this SERDEX communication system are two strobe networks. One network provides a timing pulse for synchronizing data acquisition by the various model sensors and updating or changing inflow controls.

The other strobe network provides a timing pulse to synchronize the updating of the tide controller at each of the two tide generators and the acquisition of tidal elevations at the control points of these generators. Interfacing circuitry, used with the SERDEX transmitters, has been designed such that the digital data, which were synchronously sampled throughout the model at the last strobe pulse, are held by the transmitter unit of a specific sensor until that specific sensor has been addressed by the minicomputer through a time-multiplexing of the data transmission over SERDEX system. This digital sample and hold procedure for collecting data eliminates time skew between sensor readings from various locations on the model.

19. Inflow Controls. There are 21 water inflows (Figure 17) into the model and each controller of these inflows consist of a digital valve, flowmeter, and SERDEX receiver and transmitter units. The digital valves provide precision flow rate controls by eight, internally pilotted, diaphram-type, solenoid valve actuators. Associated with each solenoid actuator is a metering flow restrictor. By selectively energizing the coils of the solenoids, any desired flow restriction can be set on the valve in increments of the smallest restriction. There are

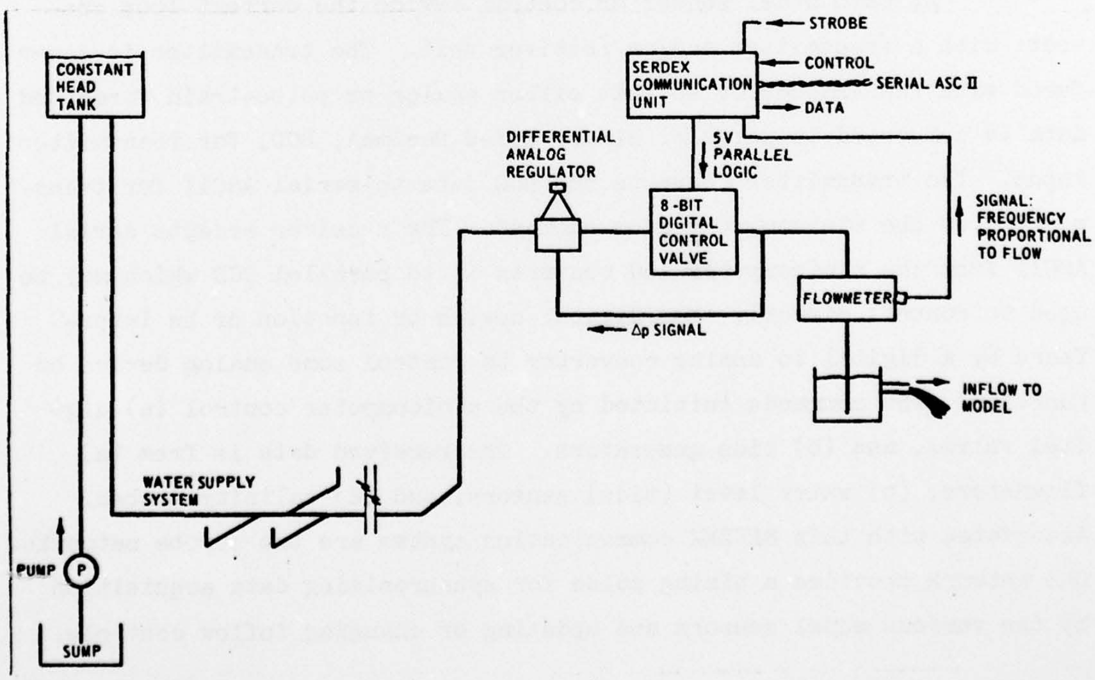

Figure 17. Schematic of Chesapeake Bay Model Inflows

256 combinations of valve settings. For each valve, an electronic interface card uses the low-level (8 bit) control signal from the SERDEX receiver to control a 120 vac signal to each solenoid. All 21 digital valves operate identically although their flow rates may be different. To provide for different flow rates, three valve sizes are used on the Chesapeake Bay model. The number and size of valves being used are 18 @ Cv = 3, two @ Cv = 9, and one Cv = 55 where the Cv number reflects the valve's flow rate that can be produced by a 1 psi drop across the valve.

At each inflow, two basic types (bearingless and fluidic) of flowmeters are used to monitor the specified flow rates. The bearingless flowmeter (0.01 to 2.0 gal/min) has a small metering chamber in which a small disk is seated. Small jets inject the fluid into this chamber at an angle which is nearly tangential to the chamber's circular wall. As the fluid spirals through the chamber, it spins the small disc which rotates on a thin film of fluid without contact with the chamber's wall. Light-reflective marks on the rim of the disc are sensed through an optical window by a photodetector which produces a time series of electrical pulses whose frequency is a measurement of flow. A four digit BCD, counter-latch circuitry was designed to be used with the SERDEX transmitter and to count the electric pulses from the bearingless flowmeter over the time interval between strobe pulses from the minicomputer. The fluidic flowmeter (2 to 155 gal/min) is a unit whose meter body is a fluidic oscillator whose frequency of oscillations is proportional to flow rate. These oscillations are detected by a flush-mounted sensor and are conditioned by the electronics to provide a 4 to 20 ma analog output signal. This signal is further conditioned to provide a 2 to 1 volt signal which is measured by a digital voltmeter in the SERDEX transmitter unit.

20. Water Level Sensors. Ten high precision water level sensors (Figure 18) were designed[8] and built at the Waterways Experiment Station for use on the Chesapeake Bay model. This physical model's requirements for water level sensors were more restrictive than other physical models and could not be met by existing sensors at the Waterways Experiment Station or from commercial sources. To meet the model's measurement

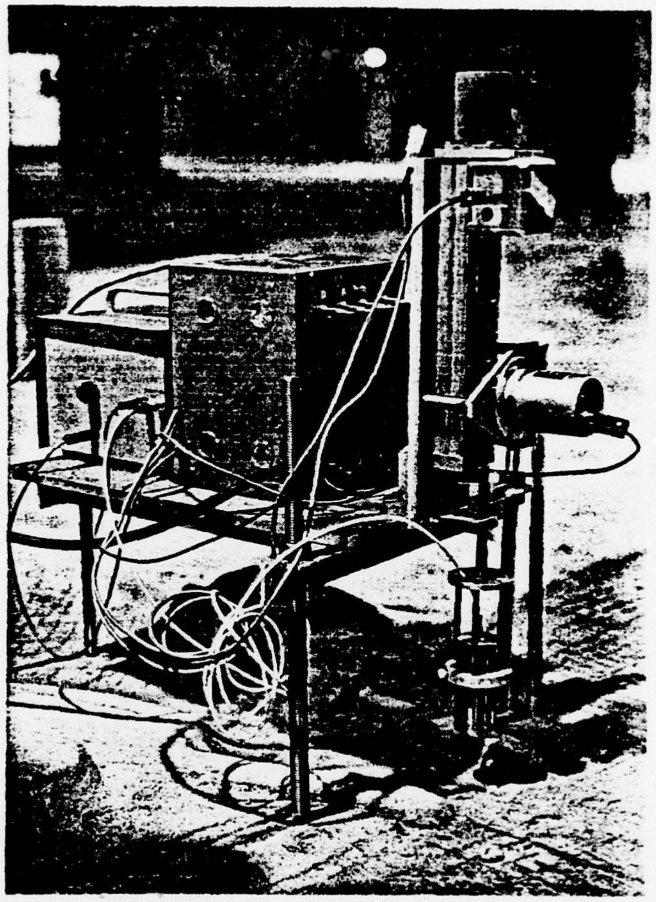

Figure 18. Chesapeake Bay water level sensor

needs, the design requirements for the water level sensor were as follows:

a. Displacement range 0.5 foot

b. Accuracy 0.001 foot

c. Resolution 0.0005 inch

d. Temperature range 32 to 110°F

A survey of potential techniques resulted in a design choice of a servo-type mechanism with a noncontacting water surface sensor. The noncontacting sensor avoids contamination problems which would be experienced by contacting type sensors. This sensor consists basically of a stainless steel capacitance probe, closed loop servo system, and an analog voltage generator.

A functional diagram of the sensor is shown in Figure 19. A distance measuring device, which is an integral part of the sensor, makes use of a capacitance probe to convert a distance into a DC voltage. The electrical capacitance formed between the capacitance probe (cp) and the water surface is used as a measure of the air gap or probe-to-water-surface distance. Changes in the water surface elevation appear as d-c voltage changes in the probe's output signal. This probe is a link in a closed loop servo system which maintains a constant distance between the capacitance probe and the water surface. The analog voltage output of the capacitance probe is directly proportional to changes in the water surface. This capacitance probe possesses high stability and excellent repeatability. The range of changes in water surface elevations to which the capacitance probe can respond is directly proportional to the probe's diameter. The capacitance probe, which was selected for the water level sensor, has a maximum diameter of 3 in., and has a maximum range of 0.5 in. To expand the sensor range for water elevation changes,

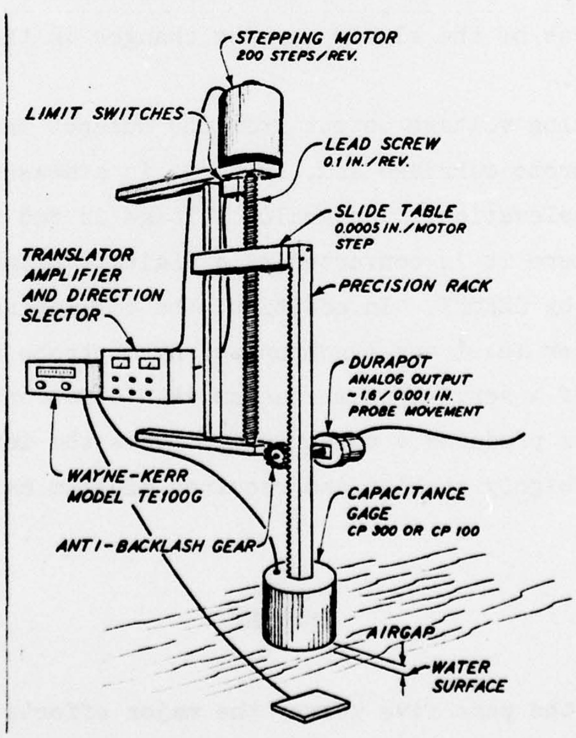

Figure 19. Schematic of capacitance sensing probe

a close-loop servo mechanism was employed with the capacitance probe.

The servo mechanism uses a precision slide table which is driven by a lead screw (6.5 in. size) and a stepping motor. This table is attached to a precision rack on which the capacitance probe is mounted. The movement of the rack or probe carriage is measured by a very accurate, potentiometer (Durapot) whose shaft is coupled by an antibacklash gear to the slide table. The control unit for the closed-loop servo system, which maintains a constant distance between the capacitance probe and the water surface, contains dual d-c power supplies, bidirectional stepping motor control, and a control module which selects servo direction and has adjustments for stepping rate, sensitivity, and spacing between probe and water surface. The output voltage from the capacitance probe goes to a control unit where stepping motor direction is determined and a triggering signal is fed to the stepping motor whose stepping rate is preselected. Thus, the up, down, or zero movement of the capacitance probe can be controlled such that the probe is always a preselected, constant distance from the water surface, regardless of the slowly varying changes in the elevation of the water surface.

The analog voltage output from the Durapot indicates the movement of the probe carriage and, in turn, is a measure of the changes in water surface elevation. The analog voltage is fed to an interfacing circuit where it is converted by a digital voltmeter to BCD data for transmission by SERDEX. In addition, the collecting of these digital values of water level are synchronized by a strobe network. The above technique of a servo-type mechanism with a noncontacting water surface sensor has produced a sensor which meets the initial design requirements, is highly stable, and requires minimum maintenance and calibration.

SUMMARY

21. During the past five years, the major efforts of automating physical, hydraulic models in the Hydraulics Laboratory at the U. S.

Army Engineer, Waterways Experiment Station have culminated in the design, development, and operation of the four ADACS for New York Harbor model, Los Angeles and Long Beach Harbor model, Chesapeake Bay model, and a multi-model application. Each of these systems has been discussed in detail including model sensors and controls which are integral parts of each system. The application of ADACS to physical modeling techniques has (a) reduced the required time for model testing programs with a related cost and manpower reduction for physical model studies, (b) increased the quality and quantity of model data by improving model sensors, and (c) allowed more sophisticated procedures for model control and data analyses. In addition to these major automation efforts, there have been other automation efforts of smaller magnitude within the Hydraulics Laboratory. In particular, physical models of water quality studies in the Structures Division have been partially automated as to data acquisition by using remote inputs to a time-sharing system on a Honeywell G-635 computer at the Automated Data Processing Center of the Waterways Experiment Station. All of these automation efforts of physical hydraulic model studies have been highly successful in demonstrating their capability of improving modeling techniques, enhancing and extending modeling capabilities, and increasing the efficiency of such procedures through time and cost savings. Future efforts for model automation in the Hydraulics Laboratory at the Waterways Experiment Station include additional automated and improved sensors, spectral wave generation, and expansion of ADACS capabilities to other model facilities with some expansions presently under way and others being planned.

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